Lab 3. Static Magnetic Fields

Name: ___________________________

Section: ___________________________

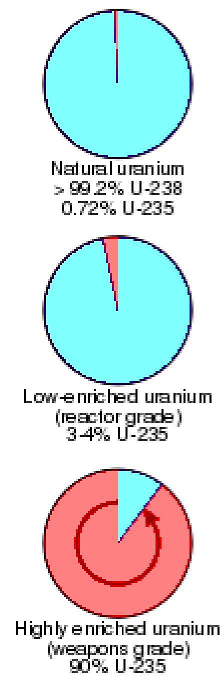
Due at the start of Lab

Task 5. The Nuclear Inspector

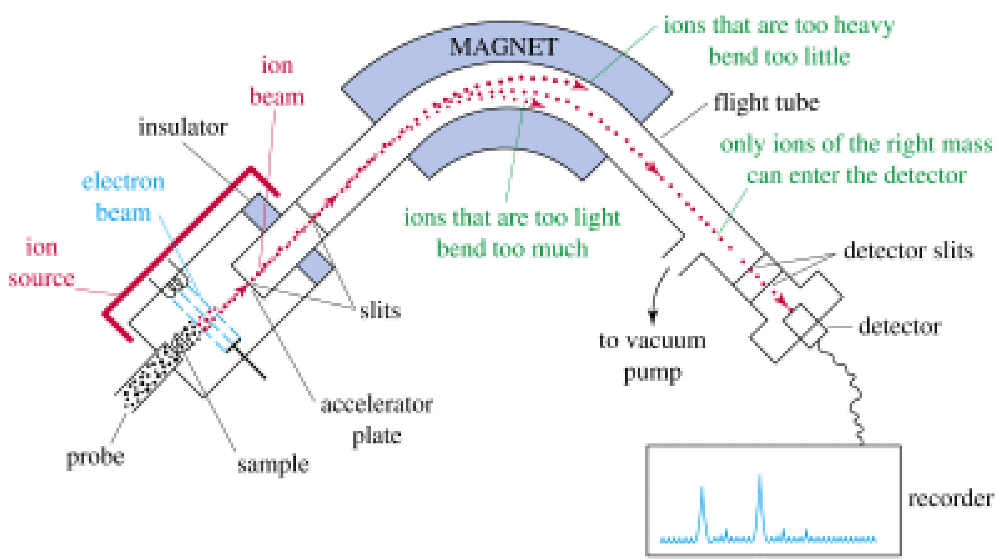
Uranium is a chemical element with 92 protons. It can have between 141 and 146 neutrons. Thus, the atomic mass of the uranium isotopes ranges between 233 and 238.

In nature, uranium atoms exist as uranium-238 (99.284%), uranium-235 (0.711%), and a very small amount of uranium-234 (0.0058%).

Many contemporary uses of uranium exploit its unique nuclear properties. Uranium-235 has the distinction of being the only naturally occurring fissile isotope. While uranium-238 has a small probability to fission spontaneously or when bombarded with fast neutrons, the much higher probability of uranium-235 to fission when bombarded with slow neutrons generates the heat in nuclear reactors. However, it is not only used as a source of power, but also provides the fissile material for nuclear weapons. In reactor-grade uranium, the U-235 fraction is increased to a level of 3–4%, whereas in weapons-grade uranium U-235 is at a level of ~90%.



You are a member of the International Atomic Energy Agency (IAEA) and have been assigned to visit a nuclear facility of a nation that is suspected of enriching uranium 235 for the purpose of making a nuclear weapon. They claim that they are pursuing only peaceful uses of nuclear material, but you suspect otherwise. After much negotiating, your team has been granted access to their enrichment facility and you have been sent to inspect the mass spectrometer measurement system. The mass spectrometer is used for periodical checks of samples out of the gas centrifuge system to see how enriched the uranium is. A schematic of the mass spec can be seen below.



A Java applet showing the operation of a mass spec may be found at
http://www.magnet.fsu.edu/education/tutorials/java/singlesector2/index.html .

Rather than a magnet as shown above, the magnetic field is generated by a large coil producing uniform magnetic field perpendicular to the plane of the drawing. The material to be examined is bombarded with electrons and ionized in the ion source chamber. Then the ions are accelerated in a strong electric field, by applying high voltage **(set by the operator**) to the accelerator's plate. The charged particles' trajectories are later altered by the magnetic field so that only one particular isotope reaches the detector (assuming all ions begin at rest and are singly ionized, i.e., only one electron has been knocked off the atom).

In order to measure a few samples and see if they are weapon-grade, you need the calibration curve of the mass spectrometer. However, you could not find the curve among the instrument documentation, so you decide to figure it out from the available data.

What is the calibration curve (dependence of what on what) and how is it being used?

Task 6. A Friend in Need's a Friend Indeed

Your best friend is an ophthalmologist and has a small but lucrative practice. One day, you receive an urgent call from him. He sounds anxious and the reason is the following: An iron filing has gotten into the eye of one of his wealthiest patients. Sure enough, the gentleman has immediately arrived at the clinic. While your friend is getting ready for the routine operation of ferromagnetic foreign body extraction from the eye, he suddenly discovers that the hand-held electromagnet doesn't work. Of course, his first thought is to ask you for help because you are a design engineer with a company producing capacitors, inductors and other electrical devices. You sense that the young ophthalmologist is about to push the panic button, therefore you take off on the spur of the moment.

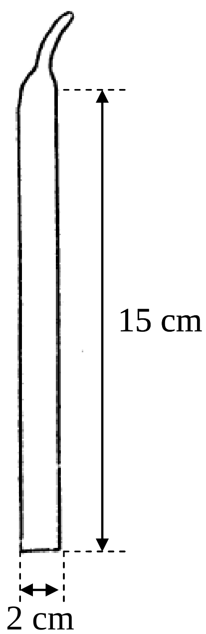


Fig. 1

The principle of operation of the hand-held electromagnet is the following: The ferromagnetic core has a long cylindrical part and a short thin tip, as shown in figure 1. Multiple turns of wire are wound on the cylindrical part of the core, thus forming a solenoid. The solenoid produces a strong magnetic field at the tip of the core. The field lines are shown in figure 2. In the region denoted by A in the figure, there is a strong gradient in the magnetic field intensity, which gives rise to the magnetic force of attraction experienced by a body with a non-zero magnetic moment.

At the clinic, you look up the properties of the magnet and find out that the core material has relative permeability of 1190, the length of the cylindrical part, where the windings are, is 15 cm, and the diameter is 2 cm. The magnet is fed by a 9-V battery and the magnetic flux density in the cylindrical part of the core is supposedly 9000 gauss.

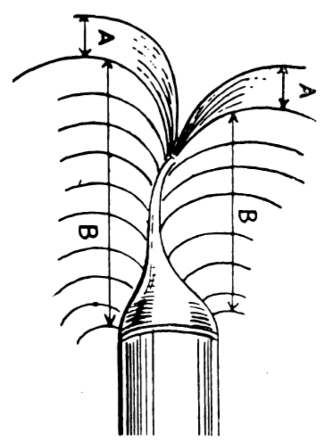


Fig. 2

You quickly discover that the electromagnet has burned out and you need to rewind the coil. Since you have expected something of the kind, you've brought a pocketful resistors and a spool of enamel copper wire ($\sigma = 5.7 \times 10^7$ S/m). The wire has a diameter of 0.2 mm. This diameter accounts for both the copper and the enamel layer. The diameter of the copper only is 0.18 mm. The maximum permissible current density in the wire is 2.55 A/mm^2.

What is the maximum permissible current through the wire you've brought?